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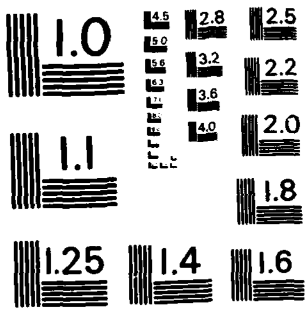

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DEPARTMENT OF DEFENCE SUPPORT

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

MECHANICAL ENGINEERING NOTE 391

CLOUD LIQUID WATER CONTENT MEASURING EQUIPMENT FOR THE NOMAD N24 AIRCRAFT FLIGHT ICING TRIALS OF 1978-1979.

Compiled

by

F. W. Skidmore

and

G. F. Pearce

Approved for Public Release.

SEPTEMBER 1981

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SUMMARY

This report describes spray rig tests on the liquid water content meters used in the Nomad N24 aircraft anti-icing trials held in 1978-1979. One instrument was based on a prototype designed by the CSIRO. A complete evaluation of this instrument was undertaken. The other was commercially available and accepted for flight icing trials use by the US Federal Aviation Authority and the Australian Department of Transport.

Provided certain precautions were taken, both instruments performed satisfactorily over the range of liquid water contents and airspeeds required for Nomad certification.

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CONTENTS

NOMENCLATURE

A	Cross sectional area of spraying airstream (m^2)
B	A constant, dependent on Reynolds Number
C	Specific heat of water (J/kg.K)
d	Hot wire target diameter (m)
E	Hot wire target supply voltage (V)
H	Rate of heat flow per unit area (W/m^2)
k	Thermal conductivity of air (W/m.K)
k_1	Thermal conductivity of clear air (W/m.K)
k_2	Thermal conductivity of air in cloud (W/m.K)
l	Hot wire target length (m)
L	Latent heat of evaporation of water (J/kg)
m_w	Liquid water flow rate of spray (kg/sec)
n	An exponent, dependent on Reynolds Number
N_{u_d}	Nusselt Number of hot wire element based on diameter
P	Power in target element (W)
P_{d_1}	Hot wire element dry power loss—clear air (W)
P_{d_2}	Hot wire element dry power loss—in cloud (W)
P_r	Hot wire element radiation loss (W)
P_w	Hot wire element wet loss (W)
P_{tot}	Element total power—in cloud (W)
R_e	Hot wire element Reynolds Number
R_1, R_2, R_3	Bridge resistors (ohms)
R_L	Hot wire element connector lead resistance (ohms)
R_w	Hot wire element resistance (ohms)
R_{w_0}	Hot wire element resistance at room temperature (ohms)
T_a	Air temperature (°C)
T_{a_1}	Air temperature—clear air (°C)
T_{a_2}	Air temperature—in cloud (°C)
T_o	Room temperature (°C)
T_h	Temperature of hot wire target housing (°C)
T_{sky}	Effective sky temperature (°C)
T_s	Effective temperature of target element surrounds (°C)

T_w	Target element wire temperature (°C)
V	Velocity of water drops relative to element (m/s)
V_1	Velocity of air relative to element—clear air (m/s)
V_2	Velocity of air relative to element—in cloud (m/s)
υ_1	Kinematic viscosity of air—clear air (m^2/s)
υ_2	Kinematic viscosity of air—in cloud (m^2/s)
w	Liquid water content of air (kg/m^3)
α	Temperature coefficient of resistivity of the target element copper wire (ohms/K)
ε	Emissivity of target element surface (assumed = 0·80)
σ	Stephan-Boltzman constant ($5 \cdot 6 \times 10^{-8}$ $W/m^2.K^4$)

1. INTRODUCTION

For the series of anti-icing trials conducted on the Nomad N24 aircraft during 1978-79, measurements were required of liquid water content (LWC) in the airstream reaching the aircraft when operating in natural cloud, or in an artificial cloud created by a tanker aircraft equipped with a boom sprayer. Accordingly, Government Aircraft Factory—Department of Industry and Commerce, who were the prime testing establishment, arranged the purchase of a Johnson-Williams LWC meter, which is manufactured in the United States of America and is accepted by the US Federal Aviation Authority (FAA) for use in anti-icing investigations. However, because there was some doubt whether the instrument could be delivered in time for the proposed trials and whether it was suitable for use in simulated clouds, ARL was asked to advise and assist in the provision of an alternative instrument.

It was found that the CSIRO Division of Cloud Physics had recently developed an LWC meter (see King, Parkin and Handsworth, 1978) which was likely to overcome some of the suspected defects of the Johnson-Williams instrument. However, the CSIRO instrument was a prototype model and not fully developed for airborne use. Moreover it had not yet been approved by either the Australian or American airworthiness authorities. A joint ARL/GAF decision was taken to build a CSIRO type instrument to Department of Transport (DOT) quality assurance standards for use in an aircraft environment, to calibrate it, and to use it either alone or simultaneously with the Johnson-Williams instrument in local tanker trials and subsequent flight trials in the United Kingdom. In the event, the Johnson-Williams instrument did arrive in time, so that both instruments were able to be used simultaneously.

This report describes both instruments and discusses the results of some tests using a ground based experimental spray rig.

2. PURPOSE OF TESTS

Test objectives were:

(a) to establish calibration factors and methods of computation of LWC for the CSIRO instrument, and to determine the individual calibration of several hot wire elements for it.

(b) to investigate the accuracy of measurement of LWC by both instruments when operating with artificially produced spray clouds sometimes containing larger drops than those present in natural clouds.

(c) to gather information on the reliability of the CSIRO LWC meter for presentation to DOT if needed.

(d) to gain experience with both types of LWC devices before flight trials began.

3. THE LIQUID WATER CONTENT METERS

3.1 General Principles

The LWC meters discussed in this report are both based on the operating principle that the heat required to evaporate all the spray or cloud drops that strike a heated target is simply related to LWC.

In order to establish a reliable calibration, the geometry of the heated portion of the target must be accurately known and should intercept a known and constant cross section of the flow; that is, the streamlines of the flow up to the target should be parallel and the upstream velocity should equal that of the free stream. For this reason, either the measuring head should itself be anti-iced, or its geometry should be such that ice build-up on the target supporting structure should not change the velocity of flow over the target. It is important that the dimensions of

the target be large relative to those of the largest drops which are likely to be encountered in the cloud as this will ensure that only a small proportion of these large drops will fail to directly hit the target. It is also important that the target be small enough to ensure efficient capture of the smaller drops from the airstream passing round it (see Jiusto, 1967).

Other desirable criteria are ruggedness and reliability when subjected to high vibration levels, and compatability of readings with the test aircraft data recording system. Although a direct-reading instrument is desirable, emphasis was placed, during the anti-icing tests, on ease of computation of LWC readings using previously established calibrations.

3.2 The Johnson-Williams LWC Meter

The Johnson-Williams LWC meter target is a single wire 0·5 mm diameter × 25·4 mm long, set transversely to the airflow and connected electrically as one arm of a constant current a–c Wheatstone bridge. A second identical wire mounted in the measuring head is set to align with the direction of flow; it is connected in the bridge circuit as a balancing arm, to compensate for the effects of air velocity and temperature, without being subject to impinging water drops. The bridge is initially balanced in dry air at the appropriate velocity, the current through both arms of the bridge being such as to maintain the wire at a temperature high enough to evaporate water drops falling on it. Evaporation of impinging water drops lowers the wire temperature and causes a change in resistance to that arm of the bridge; the unbalanced current is related to the mass of water evaporated in unit time. For a given projected area of target, the LWC is proportional to the mass of water evaporated per second divided by air velocity. A direct reading of LWC may be obtained by adjusting the bridge to compensate for airspeed. Such an adjustment, by means of a calibrated potentiometer, was provided on the instrument, but the lowest airspeed at which the instrument had been calibrated was 150 knots which was above the speeds used in the Nomad trials. All readings therefore required adjustment in the ratio of the instrument-set airspeed to the actual airspeed.

Figure 1 shows the instrument measuring head, as fitted to the aircraft. Also shown in the figure is the larger CSIRO measuring head. The supporting strut and the protective shield of the Johnson-Williams device were electrically heated to prevent ice build up.

This type of instrument has been criticised in the laboratory, (see Spyers-Duran, 1968 and Knollenberg, 1972) on grounds of small wire size, which gives inefficient capture of droplets greater than 30 microns; excessive wire temperature under some conditions, which causes droplets to "fizz" off without wetting the surface; low signal to noise ratio at low LWC conditions, and zero drift arising from progressive wetting of the compensating wire. When operating in clouds of rapidly changing LWC, the response of the instrument was claimed to be slow, leading to errors. Finally, because the bridge current is fixed, "saturation" of the wire, i.e. incomplete evaporation, can occur at higher liquid water contents.

3.3 The CSIRO LWC Meter

3.3.1 Original design

The CSIRO LWC meter (see King *et al.*, 1978) was designed to eliminate most of the alleged shortcomings of the Johnson-Williams instrument. For this reason, a constant-temperature target is used in an electrical circuit utilising hot-wire anemometry technology. By using the resistance of the target element itself as a measure of its temperature, the power input to the element can be varied to balance the heat losses due to convective heat transfer to the airstream plus the heat required to evaporate water drops impinging on it. Hence, the difference between the measured power input to the element and that required to balance convection losses (determined theoretically or by calibration in dry air) is a direct measure of the heat of evaporation of the water, and hence, of the rate of water impingement.

The target element, as originally designed, is shown in Figure 2. It consists essentially of a coil of double-enamelled 42 SWG (0·102 mm diameter) copper wire closely wound on a cupro-nickel supporting tube 1·6 mm diameter, to form an element 38 mm long by 1·8 to 1·9 mm diameter. This element has a nominal resistance of 3·75 ohms. Considerable difficulty was experienced in accurately winding these coils, so that a variation in resistance of ±0·25 ohms

FIG. 1 THE TWO LWC MEASURING HEADS MOUNTED ON THE NOMAD N24.
TOP – CSIRO TYPE, BOTTOM – JOHNSON-WILLIAMS TYPE.

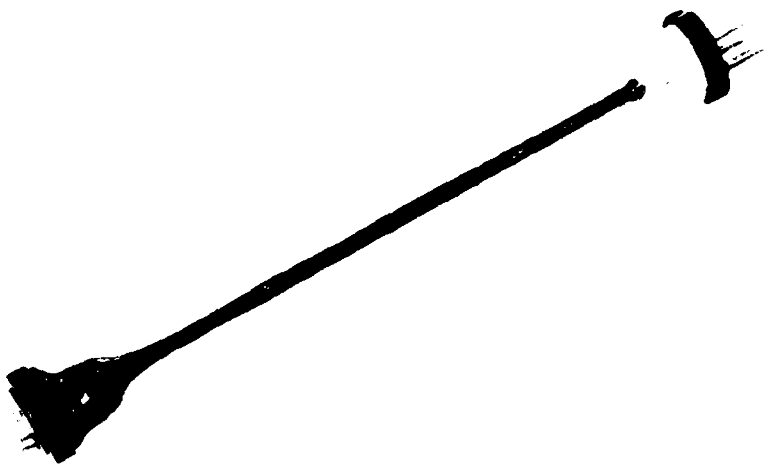


FIG. 2 ORIGINAL CSIRO HOT WIRE SENSING ELEMENT

could occur between nominally identical elements. Buffer or slave windings of the same gauge wire, 19 mm long, were located at each end of the target element to minimise axial heat losses. These were connected in series and maintained at approximately the same temperature as the target element by using the same controlled voltage source.

Inspection of the schematic circuit diagram shown in Figure 3 shows that the target element is arranged in a Wheatstone bridge circuit. The voltage imbalance of the bridge circuit is fed to a high-gain precision differential operational amplifier. The output of the amplifier controls, via a Darlington Power transistor pair, the voltage applied to the end of the bridge. Cooling the element causes an unbalance of the bridge. This results in an increase of the supply voltage and consequently an increase in the power supplied to the element, until the set resistance, and hence the designated temperature, is re-established. From a knowledge of the bridge constants, the power input to the wire can be computed as a function of the supply voltage.

This instrument has the following distinctive features:

(i) the target diameter is large, therefore large drops can be efficiently collected and evaporated.

(ii) target temperature can be controlled to just below the point where nucleate boiling of the water drops occurs.

(iii) no zero drift.

(iv) rapid response.

(v) because power input balances the power to evaporate the water, saturation does not occur at the higher LWC values.

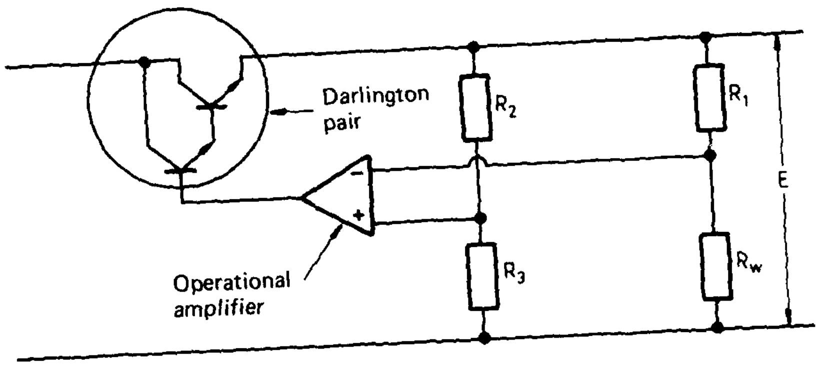
One disadvantage is that the ratio of convective heat loss to evaporative heat loss is high at low LWC values, so that accurate measurement of such values demands a very accurate knowledge of the convective or "dry" power loss as a function of air temperature, velocity and density.

3.3.2 Modified design

The original CSIRO LWC meter was a laboratory-standard prototype not designed to withstand the conditions of vibration, temperature and acceleration specified for a DOT-approved aircraft installation. A joint ARL/GAF effort was therefore undertaken to develop the instrument to DOT approved standards; it encompassed design and manufacture of the probe element and measuring head assembly and of the instrument package. In addition, GAF undertook to devel ıp a computer programme, based on ARL calibration tests, to determine LWC from the instrument readings, outside air temperature, and aircraft velocity. Some details of the design are as follows:

(a) *The Probe Element.* The original CSIRO design used a double ended configuration as in Figure 2, electrical connections being taken out through simple plugs of commercial (non aircraft) design. This construction was difficult to remove from the housing, and caused ice build-up not only on the unheated Araldite end fillets but also around the outside of the probe housing on the "flying lead" which was needed to electrically connect the outboard plug. The plugs themselves were not of DOT-approved design. A new design based on a single ended construction was therefore adopted. This is shown in Figure 4a. The outboard end of the probe was simply supported (Figure 4b); this enabled elimination of the outboard plug, and termination of all windings in a recessed Cannon connector of approved design. This arrangement made target element interchange easier, and removed most areas of ice build-up. It also permitted the insertion of a thermocouple into the bore of the element support core, thus enabling accurate measurement of the preset element winding temperature during calibration. Development of a technique for manufacturing these elements is given in Repacholi (1982).

(b) *The Measuring Head.* The measuring head was a simple 100 mm diameter stainless steel tube mounted on a ri[illegible] pylon attache[illegible] to the aircraft for the flight trials. A fixed recessed Cannon socke[illegible] [illegible]nted the [illegible] of the probe element, at the same time locating the target winding to face [illegible] trea[illegible] i.e., with outboard winding terminations on the



R_1 & R_3 – fixed resistors

R_2 – resistor matched to element resistance

R_w – hot wire element resistance

FIG. 3 SCHEMATIC CIRCUIT DIAGRAM OF CSIRO TYPE LIQUID WATER CONTENT METER

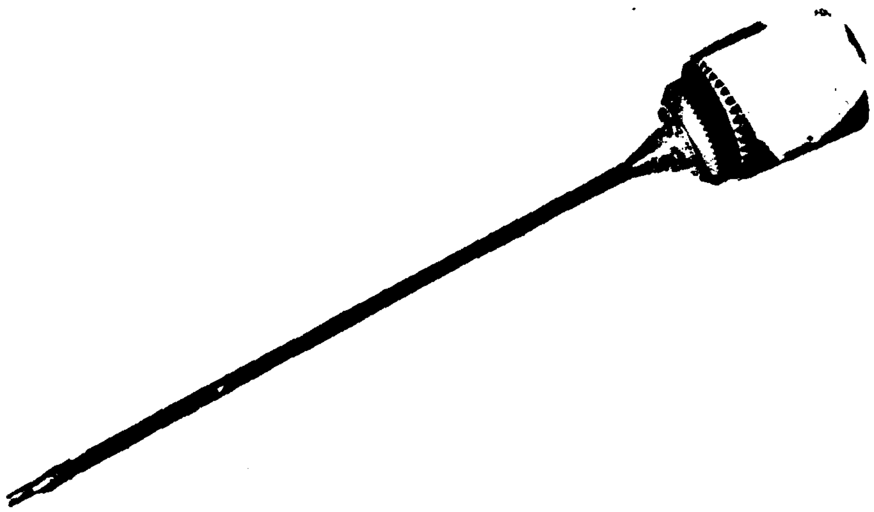


FIG. 4a THE MODIFIED CSIRO TYPE HOT WIRE ELEMENT

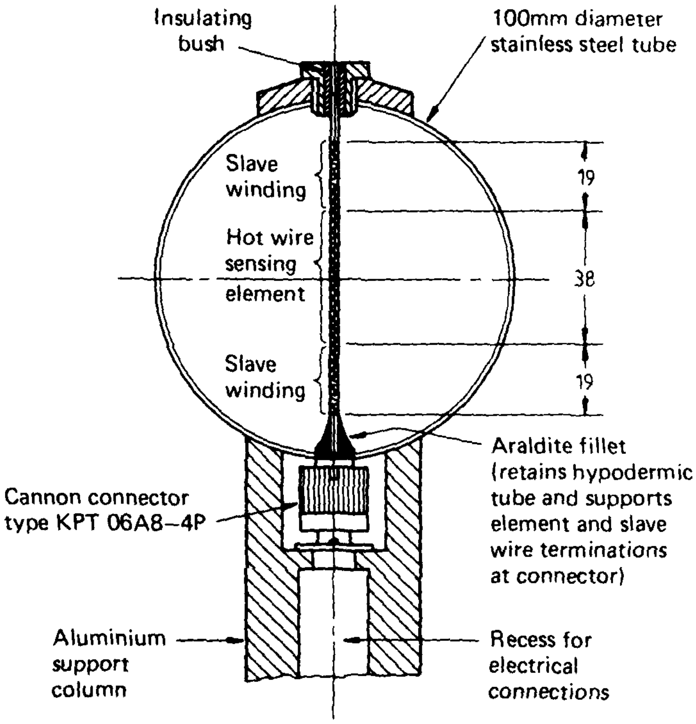


FIG. 4b SCHEMATIC LAYOUT OF THE MEASURING HEAD

downstream side. To avoid electrical earth loops and to prevent vibration, a thin nylon sleeve was used to protect the outboard end of the probe. (Further details are given in Repacholi, 1982). A photograph of the measuring head attached to the aircraft is shown in Figure 5.

(c) *The Instrument Pack*. The instrument pack had to be carefully designed because:

(i) a compact, lightweight design was essential as space within the Nomad cabin was restricted.

(ii) the instrument had to be constructed to pass Department of Transport airworthiness tests.

(iii) the aircraft d–c supply was "noisy". This necessitated internal voltage regulation and a diecast metal case for shielding.

(iv) two instrument packs with identical characteristics were required. One instrument was required to determine dry power losses (see Section 6.1) for new probes at the testing facility at ARL while the other was permanently mounted in the aircraft.

The circuit is shown in Figure 6; the four basic parts detailed are: the Error Amplifier, 22 volt Regulator, Averaging Circuit and the Indicator Circuit.

The operation of the Error Amplifier, which uses standard hot wire anemometry techniques, is discussed in detail in Section 3.3.1. The accuracy of measurement is mainly dependent on the precision resistances used in the bridge and the resistance of the hot wire probe: all resistances were determined using a Wheatstone bridge.

The indicator circuit supplied a visual indication to the operator that the instrument was functioning correctly. The averaging circuit was incorporated to show the average liquid water content over the aircraft data logging period.

Circuit boards in the instrument were potted in Sylgard 184 encapsulating resin for mechanical strength. Vibration tests to Department of Transport specifications were carried out on the instrument at the Government Aircraft Factory.

4. EXPERIMENTAL WORK

4.1 The Test Rig

Tests of both types of LWC meters were carried out using a free jet facility designed to produce a uniform airstream from a 250 mm diameter parallel nozzle. Water spray was injected into the airstream using an airblast atomiser having a hollow conical spray, mounted on the centre line near the exit of the nozzle. This spray was shown by Skidmore and Pavia (1979) to have a drop size distribution similar to that of natural cloud.

The measuring heads for both LWC meters were mounted one metre downstream of the atomiser and offset by about 30 mm from the centreline of the airstream to avoid being placed directly downstream of the hollow region of the spray cone. Care was taken to ensure that the actual sensing element for each LWC meter was placed in the same position for each test.

4.2 Method of Test

Each LWC meter was subjected to a series of tests at LWC's between about 0·5 gm/m^3 and 3·0 gm/m^3, and air velocities between 45 and 70 m/s (90 to 140 kts). The modified CSIRO LWC meter was initially calibrated without any water injection to adjust the element temperature and to determine the 'dry loss' calibration term.

Flow velocities were measured with a pitot static probe placed in the plane of the instrument measuring head. A rotameter was used to set water flows.

The Johnson and Williams unit is designed for a supply voltage of 115 volts, 400 hz. It was subjected to additional tests with the supply voltage varying from 105–125 volts. Both units were also subjected to a series of tests where the drop size was varied by altering the airblast pressure in the atomiser.

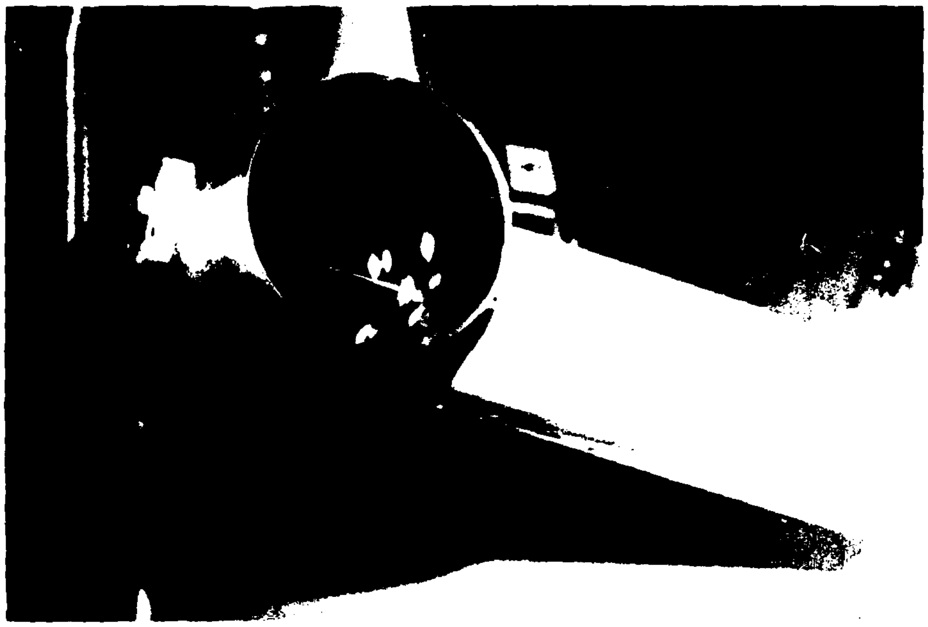


FIG. 5 CSIRO TYPE LWC MEASURING HEAD ATTACHED TO AIRCRAFT

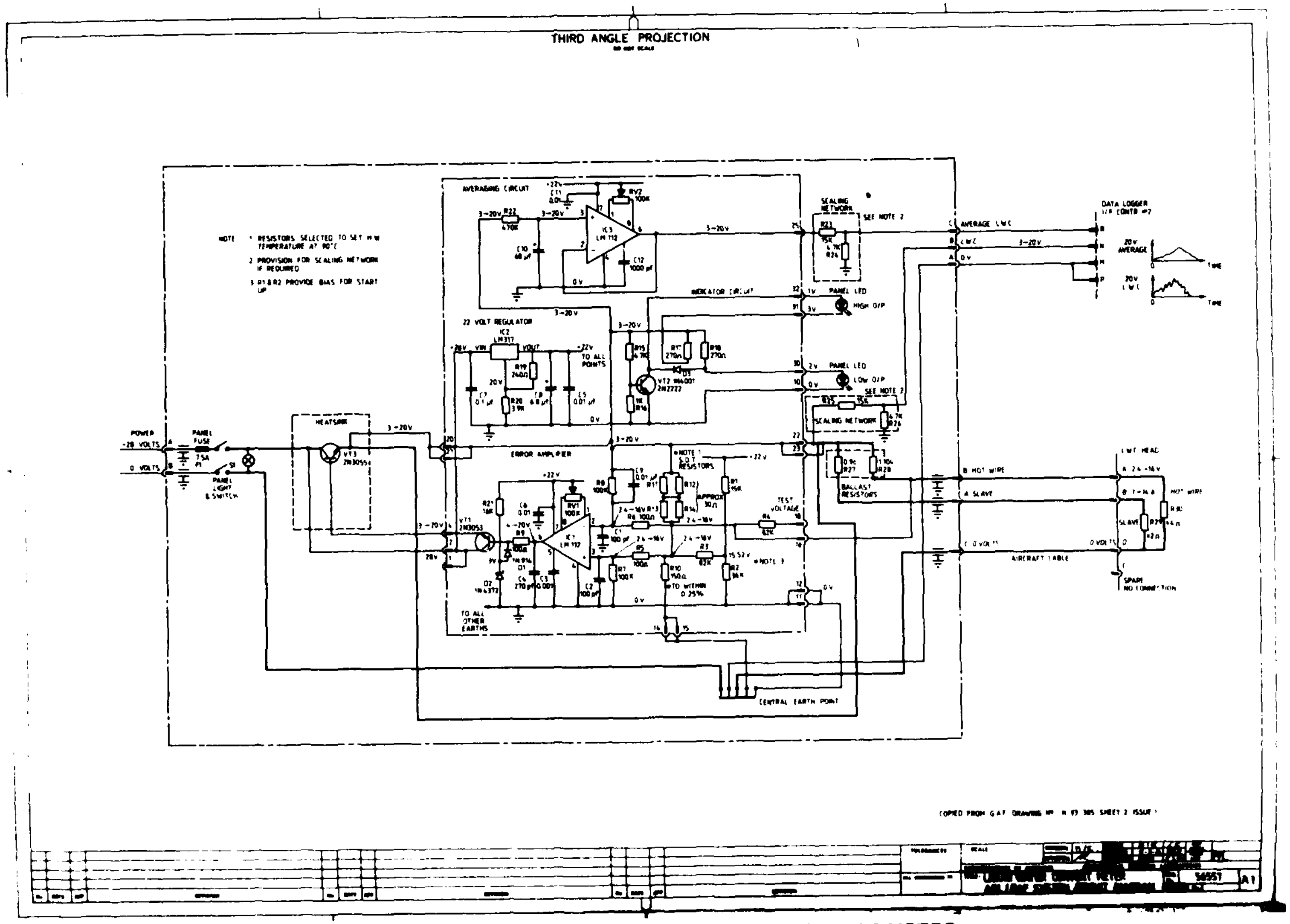


FIG. 6 CIRCUIT DIAGRAM FOR MODIFIED CSIRO LWC METER

5. COMPUTATION OF RESULTS

5.1 The Johnson-Williams LWC Meter

The Johnson-Williams instrument is a direct reading device; variations between set air-speed and true air speed require the output from the instrument to be factored by the ratio

$$\frac{\text{set airspeed}}{\text{true airspeed}},$$

assuming the instrument zero and balance are set in dry air at the same temperature.

5.2 The Modified CSIRO LWC Meter

Analysis of the circuit diagram (Figure 3) shows that

$$P = \frac{R_2 R_3}{R_1(R_2 + R_3)^2} \cdot E^2 \tag{1}$$

and when the bridge is in balance,

$$R_2 = \frac{R_1 R_3}{R_w} \tag{2}$$

where

$$R_w = R_{w_o}\{1 + \alpha(T_w - T_o)\} \tag{3}$$

For convenience, R_1 and R_3 remained fixed in value whereas R_2 was chosen to match R_{w_o} (the value of the resistance at room temperature of the particular element installed) to enable the desired wire temperature to be maintained for different elements.

King *et al.* (1978) show that the power required to maintain the heated element at a temperature T_w, is given theoretically by the expression,

$$P = ldVw\{L + C(T_w - T_a)\} + \pi lk(T_w - T_a)N_{u_d} \tag{4}$$

In this equation, the first term represents the power required to heat and evaporate water drops impinging on the target element, i.e. the 'wet' loss,

$$P_w = ldVw\{L + C(T_w - T_a)\} \tag{5}$$

The second term represents the power required to compensate for the heat loss due to forced convection in water-particulate free air, i.e. the 'dry' loss,

$$\begin{aligned} P_d &= \pi dlH \\ &= \pi lk\,(T_w - T_a)\cdot\frac{H\,d}{(T_w - T_a)\,k} \\ &= \pi lk(T_w - T_a)N_{u_d} \end{aligned} \tag{6}$$

To determine the Nusselt-Numbers, McAdams's (1954) recommends

$$N_{u_d} = B\,(R_e)^n \tag{7}$$

where

$$B = 0{\cdot}615,\ \text{and}\ n = 0{\cdot}466\ \text{for}\ 40 < \text{Re} < 4{,}000$$

and

$$B = 0{\cdot}174,\ \text{and}\ n = 0{\cdot}618\ \text{for}\ 4{,}000 < \text{Re} < 40{,}000$$

Equation (4) assumes zero heat loss in the axial direction because of the buffer windings. The analysis ignores radiation losses from the target element to its surroundings (i.e. sky and housing).

The error involved in neglecting the radiation losses is estimated with the following calculation. For a typical flight:

$$P_d = 10{\cdot}3 \text{ W (measured)}$$
$$T_w = 93\,^{\circ}\text{C}$$
$$T_a = -4{\cdot}1\,^{\circ}\text{C}$$
$$l = 0{\cdot}038 \text{ m}$$
$$d = 0{\cdot}0020 \text{ m}$$
$$V = 61{\cdot}1 \text{ m/s}$$

For flight in clear air assume

$$T_{sky} = T_a - 20 \text{ (see Duffie and Becker, 1974)}$$

and

$$T_h = T_a$$

giving

$$T_s \doteqdot -15\,^{\circ}\text{C}$$

thus

$$P_r = \pi d l \epsilon \sigma \{(T_W + 273)^4 - (T_S + 273)^4\} \tag{8}$$

i.e.

$$P_r = 0{\cdot}15 \text{ W}$$

For flight in cloud

$$\text{set } T_s = T_a = -4\,^{\circ}\text{C}$$
$$\text{then } P_r = 0{\cdot}14 \text{ W.}$$

We can convert this radiation loss into an equivalent LWC error by equating P_w and P_r from equations 5 and 8, to give;

$$w = \frac{P_w}{ldV\{L + C(T_w - T_a)\}}$$

$$\text{Setting } P_w = 0{\cdot}15 \text{ W}$$
$$L = 2260 \times 10^3 \text{ J/kg.}$$
$$\text{and } C = 4205 \text{ J/kg.K}$$
$$\text{gives } w = 0{\cdot}012 \times 10^{-3} \text{ kg/m}^3$$

The error involved in calculating the dry power loss and neglecting the radiation loss would therefore be significant only at very low LWC's (e.g. a 12% error at an LWC of $0{\cdot}1 \times 10^{-3}$ kg/m^3). Evaluation of P_d by flight trial measurement would eliminate the error altogether as the radiation loss would then be included in measured values of both P_{tot} and P_d and would cancel upon subtraction of these quantities when calculating P_w.

6. RESULTS AND DISCUSSION

6.1 Dry Power Loss—Modified CSIRO Meter

Figure 7 compares measured heat loss with calculated heat loss for all tests in the experimental rig as well as in taxi and flight trials. The results show that differences between individual probes were not significant. However on the test rig, heat losses were higher than predicted by equations (6) and (7) by between 10 and 20%. Similar results were obtained by King *et al.* (1978). This is attributed to the high turbulence level in the rig air supply; McAdams (1954), p. 261, describes how actual heat losses may in fact be up to 50 percent higher than predicted depending on the level of turbulence.

Flight and taxi trials results show a much better correlation between theoretical and actual heat losses with the exception of three flight data points, (labelled A in Figure 7). It is thought that these were the result of ice accumulating on the air temperature probe earlier in the flight

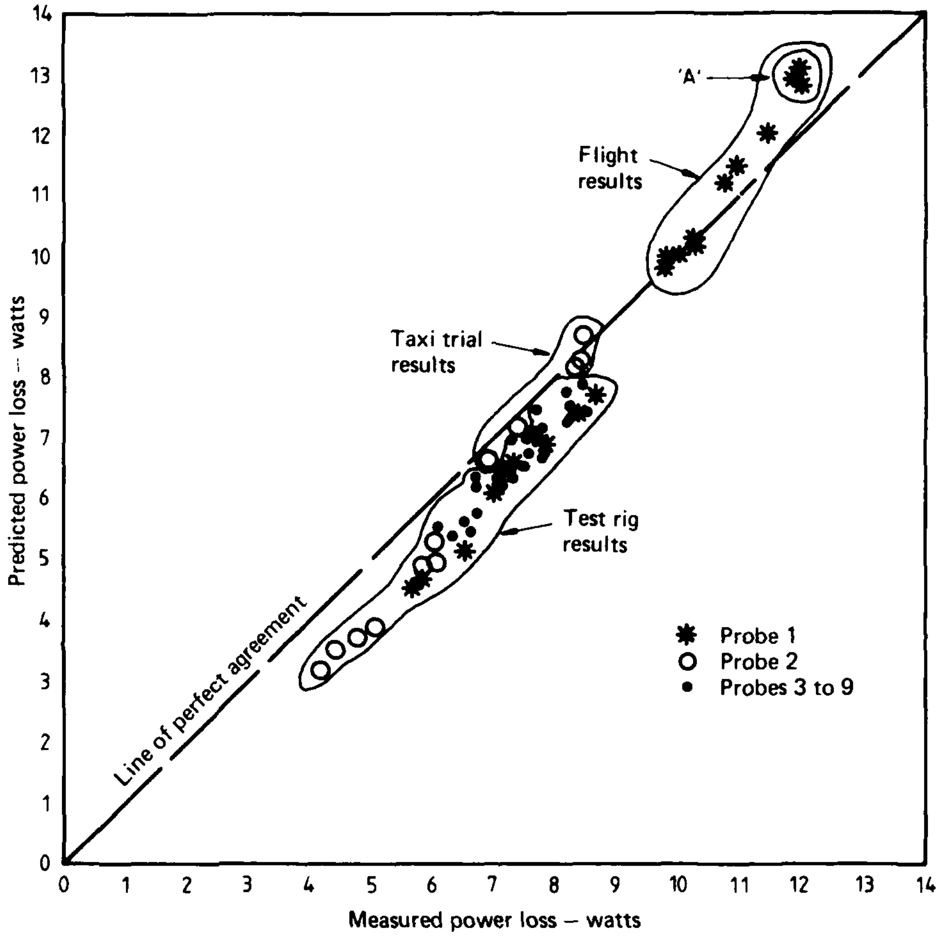


FIG. 7 TARGET PROBE POWER LOSS DUE TO CONVECTIVE HEAT TRANSFER IN DRY AIR FOR MODIFIED CSIRO LWC METER

leading to erroneous readings during the clear air test run. In one instance, ice on the probe led to a zero ambient air temperature reading even though the aircraft was back on the ground.

King *et al.* (1978) suggest that dry power losses be determined by one of the following methods:

a. Flying the aircraft in clear air at the altitude and velocity expected in cloud encounters.

Power supplied to the wire is measured and outside air temperature noted. Variations of outside air temperature and velocity can then be compensated for by modifying the clear air dry power measurement P_{d_1} according to:

$$P_{d_2} = P_{d_1}\frac{k_2}{k_1}\left(\frac{T_w - T_{a_2}}{T_w - T_{a_1}}\right)\left(\frac{\nu_1}{\nu_2}\frac{V_2}{V_1}\right)^n \tag{9}$$

which is simply derived from equations (6) and (7)

where P_{d_2} = Dry power loss—In cloud (W)

P_{d_1} = Dry power loss—Clear air (W)

The liquid water content (w) of the cloud can then be determined from

$$w = \frac{P_{tot} - P_{d_2}}{ldV\{L + C(T_w - T_{a_2})\}}$$

where

P_{tot} = Total power supplied—in cloud (W)

This method has the advantage that wire calibration is not necessary, while empirical evaluation is only used to adjust dry power losses for the in-cloud condition.

b. Carrying out sufficient flight trials to establish a Nusselt vs Reynolds number calibration for each probe.

King *et al.* (1978) suggest that this method is superior to method (a), however, valuable flight trial time is used in gathering data which must be repeated if the sensor element fails.

Considering the results shown in Figure 7 for both flight and taxi trials it would appear that empirical evaluation is sufficiently accurate. This could be tested initially with say one low level flight or taxi trial where true airspeed, outside air temperature and altitude are accurately known. Flight trials data presented by King *et al.* (1978) also shows that equation (4) is accurate.

6.2 Tests in the Spray Rig

6.2.1 Liquid water content at the measuring point

No instrumentation was available to independently measure the local LWC at the position of the meters. The mean value of LWC at the measuring plane could be simply calculated and it was assumed that the spray was uniform across the air jet. A qualitative check on this assumption was made by taking spray samples at ten different locations across the measuring plane using soot coated slides (see Skidmore and Pavia, 1979). The spray appeared to have a uniform size distribution and density over the whole jet. Airstream velocity had no noticeable effect on the drop size distribution and spray evaporation effects between the injection point and the sampling point (one meter downstream) would have been negligible according to the results of Belte, (1981).

6.2.2 Johnson-Williams LWC meter

The spray rig LWC as measured by the Johnson-Williams meter, showed repeatability only to within about $\pm 30\%$ when compared with the mean value at the measuring plane (see Figure 8). However better reliability was expected in cloud sampling because the LWC would be uniform. This proved to be the case in subsequent flight tests (see Atkins, 1982).

Contrary to expectations (see Section 3.2) the meter reading increased as the dropsize was increased above 30 μm. As the meters were required for flight work this anomoly could not be investigated.

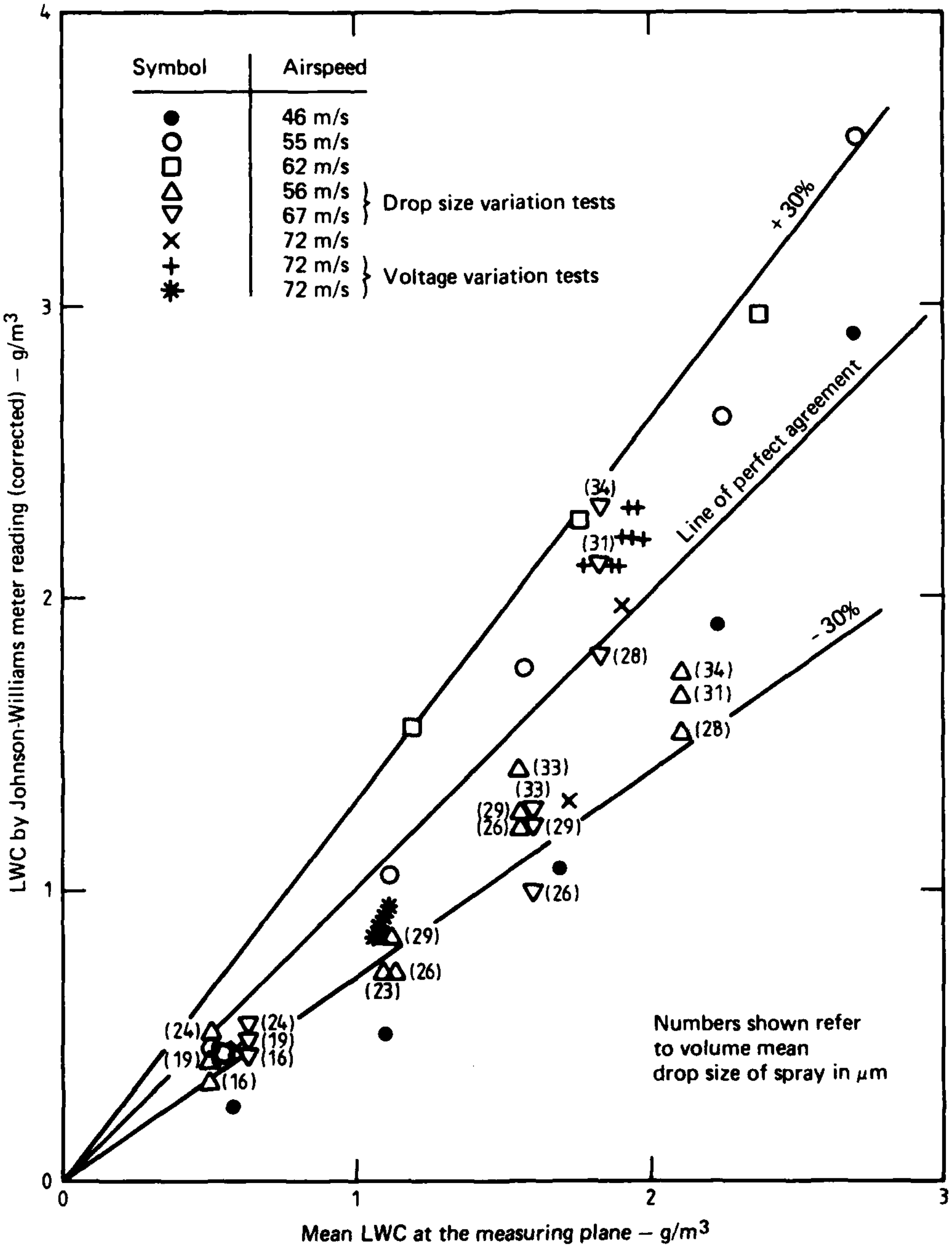


FIG. 8 JOHNSON-WILLIAMS LWC METER: MEASURED LWC VERSUS MEAN VALUE AT THE MEASURING PLANE

Tests with varying input voltage and LWC's ranging from 1 to 2 gm/m^3 showed that the meter reading reached a maximum at the nominal 115 volts but fell away as the voltage was varied either side of this value; for example by 10% for 105 or 125 volts.

6.2.3 Modified CSIRO LWC meter

Agreement between LWC measured by the CSIRO meter and the overall mean value at the measuring plane was within ±20% (Figure 9) and this was considered very good for spray rig tests. Changing predicted dry power loss due to different air turbulence levels, required an allowance to be made when relating rig calibrations to the flight situation. Adjustments were also made, when appropriate, to correct for temperature and airspeed variations during the water spray injection tests (see Section 6.1). When these corrections were applied to later flight trial results (reported in Atkins, 1982), good agreement with the Johnson-Williams instrument was achieved.

Results for a limited number of tests with varying dropsize were inconclusive; at a nominal LWC of 1 gm/m^3 the instrument reading decreased with increased drop size whereas at 2 gm/m^3 the reverse was true.

Vibration tests on the instrument were carried out by GAF to establish airworthiness. Calibration tests on the rig after the vibration tests showed no change in the instrument performance.

7. CONCLUSIONS

Two liquid water content meters—a US, commercially available, Johnson-Williams type and a modified CSIRO designed prototype—have been tested in a spray rig.

Both instruments performed satisfactorily in the spray rig for liquid water contents ranging from 0·5 to 3·0 gm/m^3, and airspeeds ranging from 45 to 72 m/s.

The LWC measurements were repeatable within a scatter band of ±20% for the modified CSIRO instrument and ±30% for the Johnson-Williams instrument. As expected, closer correlation of results for the two instruments was achieved in subsequent flight tests when LWC conditions were probably more uniform than in the spray rig.

The Johnson-Williams instrument was sensitive to changes in supply voltage as a variation of ±10% from the specified 115 volts caused the readout to fall by 10%.

When establishing, for the hot target, the Nusselt versus Reynolds number relation that determines the dry power loss characteristic of the modified CSIRO instrument, accurate measurements of temperature, velocity and altitude are necessary.

Within the LWC range appropriate to aircraft flight icing trial requirements, radiation losses from the instrument target elements are negligible.

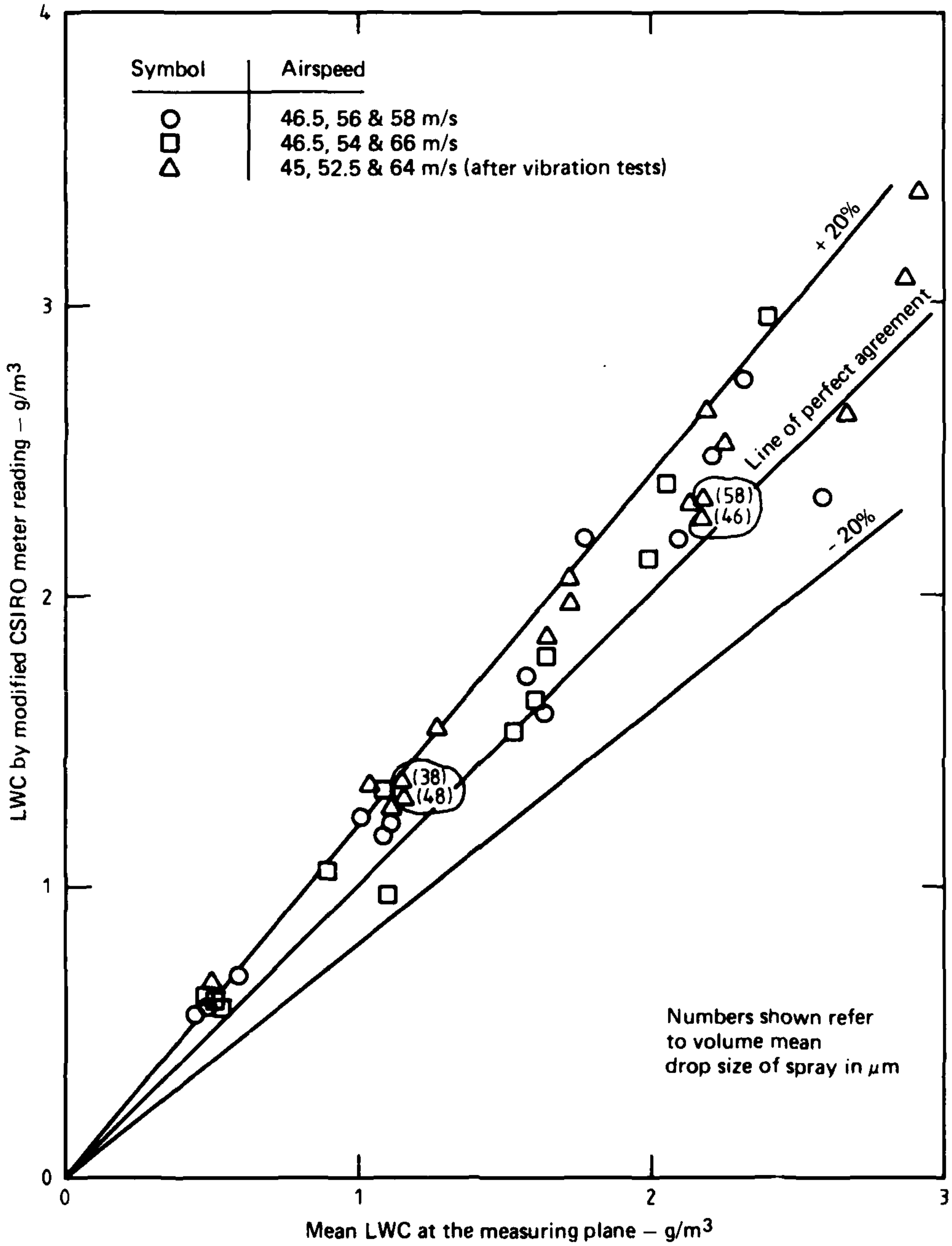


FIG. 9 MODIFIED CSIRO LWC METER: MEASURED LWC VERSUS MEAN VALUE AT THE MEASURING PLANE

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16. Abstract

This report describes spray rig tests on the liquid water content meters used in the Nomad N24 aircraft anti-icing trials held in 1978-1979. One instrument was based on a prototype designed by the CSIRO. A complete evaluation of this instrument was undertaken. The other was commercially available and accepted for flight icing trials use by the US Federal Aviation Authority and the Australian Department of Transport.

Provided certain precautions were taken, both instruments performed satisfactorily over the range of liquid water contents and airspeeds required for Nomad certification.

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